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RECENT PROGRESS IN AERONAUTICS[1]

THERE are two general classes of vehicles of the air, (*a*) those which depend for their support upon the buoyancy of some gas lighter than air, and (*b*) those which depend for such support upon the dynamic reaction of the air itself. These classes are designated:

(*a*) Lighter-than-air types:
Free balloons, dirigible balloons or airships.
(*b*) Heavier-than-air types:
Aeroplanes, orthopters, helicopters, etc.

It should be remarked, however, that these two general classes exhibit a growing tendency to overlap each other. For example, the latest dirigible balloons are partly operated by means of aeroplane surfaces, and are also often balanced so as to be slightly heavier than the air in which they move, employing the propeller thrust and rudder surfaces to control the altitude.

I. AEROSTATION

Captive and free balloons, with the necessary apparatus and devices for operating the same, have been for many years considered an essential part of the military establishment of every first-class power. They played a conspicuous part in the siege of Paris, and were often valuable in our own civil war. The construction and operation of aerostats are too well understood to need further attention here.

Although many aerodynamic data are needed for the proper design of a dirigible

[1] Abstract of an address before Section D—Mechanical Science and Engineering—American Association for the Advancement of Science, Baltimore, 1908.

airship, yet the experience already available in the construction and performance of such ships built on different plans is sufficient to enable the engineer to proceed with the design of a dirigible balloon to accomplish definite results along fairly accurate lines. In the case of this class of lighter-than-air ships the following general equation obtains:

$$W - w = V(\sigma - \sigma/n)$$

where

W = weight of balloon, envelope, car and aeronauts,
V = volume of balloon,
σ = density of the air,
n = density of air as compared with gas,
w = weight of air displaced by car and aeronauts and envelope of balloon.

If we call the weight of the gas in the balloon M, then we can write this equation in the following manner:

$$W + M = w + nM,$$

from which we find that

$$M = (W - w/n - 1)$$

and

$$V = [(W - w)/\sigma]\,[n/(n - 1)],$$

thus obtaining the volume of gas required. If the volume of the gas-bag, car, aeronauts, etc. $= v$, then $w = v\sigma$; so that the preceding equation may be written

$$V = [(W - v\sigma)/\sigma]\,[n/(n - 1)].$$

Thus far, certainly, no dirigible balloon has ever been developed which has attained an independent speed greater than forty miles per hour. It will readily be admitted that an airship so designed as to reach a speed of fifty or sixty miles per hour would be regarded as a most decided step forward in the art, since this difference of velocity is just the increment needed to place such craft on a practical basis capable of maneuvering in the air in all ordinary weather. This advancement, although requiring much consideration, would fully compensate in practical results.

The first point to be decided upon in the design of an airship is the method of maintaining the shape of the gas-bag against the pressure encountered at the maximum velocity to be attained. There are two schools of design in this respect, each having its adherents. One maintains the shape of the gas-bag by a rigid interior frame, and the other by means of the internal pressure of the gas itself.

Upon the selection of the type depends to a large extent the particular shape of the envelope. If the envelope is to maintain its shape by interior pressure of gas, evidently it must be so designed that the maximum pressure of the air developed at the speed contemplated shall not be sufficient to cause deformation of any part of the envelope. This can be effected only by making the uniform internal pressure at least equal to the maximum external pressure. Since the maximum external pressure occurs over the prow of the airship, this, evidently, is the particular part which must receive most careful attention with this system.

The desirable shape of head would evidently be one where the distribution of external pressure due to air resistance at the velocity used is uniform. In addition to preventing deformation of the gas-bag, a prime requisite also is that the shape shall be such that the total resistance, comprising head resistance and skin-friction, shall be a minimum for a given displacement and velocity.

This immediately forces the question of the law of resistance of the air. On this subject there are numerous aerodynamic data for low velocities, and also for very high velocities, but such data are incomplete for the range of velocities here considered.

In fact, the law of resistance of the air

for surfaces of revolution as experimentally determined, is known to vary not with any constant power of the velocity, but by a range of exponents from the first to the cube, if not higher. For example, in the enormous velocities attained by modern artillery, where bodies weighing a ton or more are hurled through the air at 2,000 feet per second, it is known that the physical phenomena become entirely different in nature from those found when dealing with moderate velocities such as are met in transportation devices.

If the rigid system be employed where an internal frame prevents deformation of the envelope, the stresses due to external pressure are taken up by the framework itself, and the gas required for flotation is usually contained in several separate receptacles or ballonets similar to compartments employed in ships. In this system, therefore, we are concerned only in securing such a shape of the rigid frame as will fulfill the condition of minimum total resistance for a given displacement and velocity.

Once the shape of the bag is determined from the considerations already enumerated, the dimensions become immediately fixed when the tonnage is assumed, or conversely, if any linear dimension is assigned the tonnage is thereby determined.

In addition to the two general systems above considered, there are various types involving some of the principles of each, which are classed in general as semi-rigid systems. Such systems usually comprise a rigid frame, to which is attached the gas-bag above, and the load below.

The next step is one of structural design along strictly engineering lines. The aerodynamic features of airship construction may be considered under the heads: (*a*) static balance, (*b*) dynamic balance, (*c*) stability, (*d*) natural period and oscillation.

Static Balance.—The dimensions of the gas-bag being determined, the lift of each transverse segment thereof is immediately known, and the design of the frame may proceed by approximate trial and correction as in other structural work. The weight of each segment of the envelope itself is readily computed, which, added to the corresponding segment of the frame, gives the total weight of each segment, and this total subtracted from the lift of each segment gives the net lift for that complete segment. From the magnitude and position of these net forces the position of the resultant lift is known, and this determines the vertical line through the center of gravity. Such procedure evidently insures static balance of the machine as a whole, and an approximate distribution of the load.

Dynamic Balance.—The dynamic balance must also be carefully considered; and here a difficulty has been experienced on account of the inability to place the resultant thrust coincident with the line of resistance of the ship as a whole. Heretofore, it has been customary to balance the thrust-resistance couple by means of suitable horizontal rudders or planes, so situated and at such angles that the resultant moment of the system should be zero at uniform speeds of travel, though not necessarily zero for accelerated motion.

If, however, the line of thrust be made coincident with the line of resistance, the disturbing moment in question will be eliminated at uniform speeds. If, furthermore, the center of mass be located on the line of thrust and sufficiently forward to form a righting couple with the resistance when the wind suddenly veers, the evil effects of a disturbing moment will be obviated for variable as well as for constant speeds. The ship is then dynamically balanced.

This, of course, requires that the form of hull be such that a quartering wind shall exert a force passing to the rear of the

center of mass. To illustrate, a good example of dynamic balance is found in a submarine torpedo, or a fish.

Stability.—The foregoing adjustments still allow the center of mass to be placed below the center of buoyancy. This is a provision that is important in aeronautics as well as in marine architecture; indeed, it is the only practical provision for keeping an even keel and preventing heeling when the ship is at rest, or simply drifting with the wind. If the center of gravity be well below the center of buoyancy, the vessel is proportionately stable, but, of course, the stability is pendular, and may admit of considerable rolling and pitching due to shifting loads, sudden gusts of wind, etc., unless special devices be used to dampen or prevent these effects.

Natural Period and Oscillations.—It may happen also that the equilibrium of the ship is disturbed by periodic forces whose periods are simply related to the natural period of the ship itself. In this case the oscillations will be cumulative and may become very large. Such effects are well known to marine engineers, and may be treated as in ordinary ship design.

II. AVIATION

This division comprises all those forms of heavier-than-air flying-machines which depend for their support upon the dynamic reaction of the atmosphere. There are several subdivisions of this class dependent upon the particular principle of operation. Among these may be mentioned the aeroplane, orthopter, helicopter, etc. The only one of these that has been sufficiently developed at present to carry a man in practical flight is the aeroplane. There have been a large number of types of aeroplanes tested with more or less success and of these the following are selected for illustration.

The design of an aeroplane may be considered under the heads of support, resistance and propulsion, stability and control.

Support.—In this class of flying-machines, since the buoyancy is practically insignificant, support must be obtained from the dynamic reaction of the atmosphere itself. In its simplest form, an aeroplane may be considered as a single plane surface moving through the air. The law of pressure on such a surface has been determined and may be expressed as follows:

$$P = 2k\sigma AV^2 \sin \alpha,$$

in which P is the normal pressure upon the plane, k is a constant of figure, σ the density of the air, A is the area of the plane, V the relative velocity of translation of the plane through the air, and α the angle of flight.

This is the form taken by Duchemin's formula for small angles of flight such as are usually employed in practise. The equation shows that the upward pressure on the plane varies directly with the area of the plane, with the sine of the angle of flight, with the density of the air, and also with the square of the velocity of translation.

It is evident that the total upward pressure developed must be at least equal to the weight of the plane and its load, in order to support the system. If P is greater than the weight the machine will ascend, if less, it will descend.

The constant k depends only upon the shape and aspect of the plane, and should be determined by experiment. For example, with a plane 1 foot square $k\sigma = 0.00167$, as determined by Langley, when P is expressed in pounds per square foot, and V in feet per second.

The first equation may be written

$$AV^2 = P/2k\sigma \sin \alpha.$$

If P and α are kept constant then the equation has the form

$$AV^2 = \text{constant}.$$

An interpretation of the second equation reveals interesting relations. The supporting area varies inversely as the square of the velocity. For example, in the Wright aeroplane, the supporting area at 40 miles per hour is 500 square feet, while if the speed is increased to 60 miles per hour this area need be only $500/1.5^2 = 222$ square feet, or less than one half of its present size. At 80 miles per hour the area would be reduced to 125 square feet, and at 100 miles per hour only 80 square feet of supporting area is required. These relations are conveniently exhibited graphically.

It thus appears that if the angle of flight be kept constant in the Wright aeroplane, while the speed is increased to one hundred miles per hour, we may picture a machine which has a total supporting area of 80 square feet, or a double surface each measuring about $2\frac{1}{2}$ by 16 feet, or 4 by 10 feet if preferred. Furthermore, the discarded mass of the 420 square feet of the original supporting surface may be added to the weight of the motor and propellers in the design of a reduced aeroplane, since in this discussion the total mass is assumed constant at 1,000 pounds.

In the case of a bird's flight, its wing surface is "reefed" as its velocity is increased, which instinctive action serves to reduce its head resistance and skin-frictional area, and the consequent power required for a particular speed.

Determination of k for Arched Surfaces.—Since arched surfaces are now commonly used in aeroplane construction, and as the first equation applies to plane surfaces only, it is important to determine experimentally the value of the coefficient of figure k, for each type of arched surface employed, especially as k is shown in some cases to vary with the angle of flight α; *i. e.*, the inclination of the chord of the surface to the line of translation.

Assuming α constant, however, we may compare the lift of any particular arched surface with a plane surface of the same projected plan and angle of flight.

To illustrate, in the case of the Wright aeroplane, let us assume

$$P = 1{,}000 \text{ lb.} = \text{total weight} = W,$$
$$A = 500 \text{ sq. ft.},$$
$$V = 40 \text{ miles per hour} = 60 \text{ ft. per second},$$
$$\alpha = 7 \text{ deg. approximately.}$$

Whence

$$k\sigma = P/2AV^2 \sin\alpha = 1{,}000/(2 \times 500 \times 60^2 \times \tfrac{1}{8})$$
$$= 0.0022 \quad (V = \text{ft. sec.})$$
$$= 0.005 \quad (V = \text{mi. hr.}).$$

Comparing this value of $k\sigma$ with Langley's value 0.004 for a plane surface V being in miles per hour, we see that the lift for the arched surface is 25 per cent. greater than for a plane surface of the same projected plan. That is to say, this arched surface is dynamically equivalent to a plane surface of 25 per cent. greater area than the projected plan. Such a plane surface may be defined as the "equivalent plane."

Resistance and Propulsion.—The resistance of the air to the motion of an aeroplane is composed of two parts: (a) the resistance due to the framing and load, (b) the necessary resistance of the sustaining surfaces, that is, the drift, or horizontal component of pressure; and the unavoidable skin-friction. Disregarding the frame, and considering the aeroplane as a simple plane surface, we may express the resistance by the equation

$$R = W \tan\alpha + 2fA,$$

in which R is the total resistance, W the gross weight sustained, α the angle of flight, f the friction per square unit of area of the plane, A the area of the plane. The first term of the second member gives the drift, the second term the skin-friction. The power required to propel the aeroplane is

$$H = RV,$$

in which H is the power, V the velocity.

Now W varies as the second power of the velocity, as shown by the first equation, and f varies as the power 1.85, as will be shown later. Hence we conclude that the total resistance R of the air to the aeroplane varies approximately as the square of its speed, and the propulsive power practically as the cube of speed.

Most Advantageous Speed and Angle of Flight.—Again, regarding W and A as constant, we may, by the first equation, compute a for various values of V, and find f for those velocities from the skin-friction table to be given presently. Thus a, R and H may be found for various velocities of flight, and their magnitudes compared.

The question of stability is a serious one in aviation, especially as increased wind velocities are encountered. In machines of the aeroplane type there must be some means provided to secure fore and aft stability and also lateral stability.

A large number of plans have been proposed for the accomplishment of these ends, some based upon the skill of the aviator, others operated automatically, and still others employing a combination of both. At the present time no aeroplane has yet been publicly exhibited which is provided with automatic control. There is little difference of opinion as to the desirability of some form of automatic control.

The Wright aeroplane does not attempt to accomplish this, but depends entirely upon the skill of the aviator to secure both lateral and longitudinal equilibrium, but it is understood that a device for this purpose is one of the next to be brought forward by them. Much of the success of the Wright brothers has been due to their logical procedure in the development of the aeroplane, taking the essentials, step by step, rather than attempting everything at once, as is so often the practise with inexperienced inventors.

The aviator's task is much more difficult than that of the chauffeur. With the chauffeur, while it is true that it requires his constant attention to guide his machine, yet he is traveling on a roadway where he can have due warning, through sight, of the turns and irregularities of the course.

The fundamental difference between operating the aeroplane and the automobile is that the former is traveling along an aerial highway which has manifold humps and ridges, eddies and gusts, and since the air is invisible he can not see these irregularities and inequalities of his path, and consequently can not provide for them until he has actually encountered them. He must feel the road since he can not see it.

Some form of automatic control whereby the machine itself promptly corrects for the inequalities of its path is evidently very desirable. As stated above, a large number of plans for doing this have been proposed, many of them based on gyrostatic action, movable side planes, revolving surfaces, warped surfaces, etc. A solution of this problem may be considered as one of the next important steps forward in the development of the aeroplane.

III. HYDROMECHANIC RELATIONS

At the present moment so many minds are engaged upon the general problem of aerial navigation that any method by which a broad forecast of the subject can be made is particularly desirable. Each branch of the subject has its advocates, each believing implicitly in the superiority of his method. On the one hand, the adherents of the dirigible balloon have little confidence in the future of the aeroplane, while another class have no energy to devote to the dirigible balloon, and still others prefer to work on the pure helicopter principle. As a matter of fact, each of these types is probably of permanent importance, and each particularly adapted to certain needs.

Fortunately for the development of each type, the experiments made with one class are of value to the other classes, and these in turn bear close analogy to the types of boats used in marine navigation. The dynamical properties of water and air are very much alike, and the equations of motion are similar for the two fluids, so that the data obtained from experiments in water, which are very extensive, may, with slight modification, be applied to computations for aerial navigation.

Helmholtz's Theorem.—Von Helmholtz, the master physicist of Germany, who illuminated everything he touched, has fortunately considered this subject, in a paper written in 1873. The title of his paper is "On a Theorem Relative to Movements that are Geometrically Similar in Fluid Bodies, together with an Application to the Problem of Steering Balloons."

In this paper Helmholtz affirms that, although the differential equations of hydromechanics may be an exact expression of the laws controlling the motions of fluids, still it is only for relatively few and simple experimental cases that we can obtain integrals appropriate to the given conditions, particularly if the cases involve viscosity and surfaces of discontinuity.

Hence, in dealing practically with the motion of fluids, we must depend upon experiment almost entirely, often being able to predict very little from theory, and that usually with uncertainty. Without integrating, however, he applies the hydrodynamic equations to transfer the observations made on any one fluid with given models and speeds, over to a geometrically similar mass of another fluid involving other speeds, and models of different magnitudes. By this means he is able to compute the size, velocity, resistance, power, etc., of aerial craft from given, or observed, values for marine craft.

He also deduces laws that must inevitably place a limit upon the possible size and velocity of aerial craft without, however, indicating what that limit may be with artificial power. Applying this mode of reasoning to large birds, he concludes by saying that, "It therefore appears probable that in the model of the great vulture, nature has already reached the limit that can be attained with the muscles as working organs, and under the most favorable conditions of subsistence, for the magnitude of a creature that shall raise itself by its wings and remain a long time in the air."

In comparing the behavior of models in water and air, he takes account of the density and viscosity of the media, as these were well known at the date of his writing, 1873; but he could not take account of the sliding, or skin-friction, because in his day neither the magnitude of such friction for air, nor the law of its variation with velocity had been determined.

Even as late as Langley's experiments, skin-friction in air was regarded as a negligible quantity, but, due to the work of Dr. Zahm, who was the first to make any really extensive and reliable experiments on skin-friction in air, we now can estimate the magnitude of this quantity. As a result of his research he has given in his paper on atmospheric friction the following equation:

$$f = 0.00000778\, l^{-0.07} v^{1.85} \ldots (v = \text{ft. sec.}),$$
$$f = 0.0000158\, l^{-0.07} v^{1.85} \ldots (v = \text{mi. hr.}),$$

in which f is the average skin-friction per square foot, and l the length of surface.

Relative Dynamic and Buoyant Support.—Peter Cooper-Hewitt has given careful study to the relative behavior of ships in air and in water. He has made a special study of hydroplanes, and has prepared graphic representations of his results which furnish a valuable forecast of the problem of flight.

Without knowing of Helmholtz's the-

orem, Cooper-Hewitt has independently computed curves for ships and hydroplanes from actual data in water, and has employed these curves to solve analogous problems in air, using the relative densities of the two media, approximately 800 to 1, in order to determine the relative values of support by dynamic reaction and by displacement for various weights and speeds.

An analysis of these curves leads to conclusions of importance, some of which are as follows:

The power consumed in propelling a displacement vessel at any constant speed, supported by air or water, is considered as being two thirds consumed by skin-resistance, or surface resistance, and one third consumed by head resistance. Such a vessel will be about ten diameters in length, or should be of such shape that the sum of the power consumed in surface friction and in head resistance will be a minimum (torpedo shape).

The power required to overcome friction due to forward movement will be about one eighth as much for a vessel in air as for a vessel of the same weight in water.

Leaving other things out of consideration, higher speeds can be obtained in craft of small tonnage by the dynamic reaction type than by the displacement type, for large tonnages the advantages of the displacement of type are manifest.

A dirigible balloon carrying the same weight, other things being equal, may be made to travel about twice as fast as a boat for the same power; or be made to travel at the same speed with the expenditure of about one eighth of the power.

As there are practically always currents in the air reaching, at times, a velocity of many miles per hour, a dirigible balloon should be constructed with sufficient power to be able to travel at a speed of about 50 miles per hour, in order that it may be available under practical conditions of weather. In other words, it should have substantially as much power as would drive a boat, carrying the same weight, 25 miles an hour, or should have the same ratio of power to size as the *Lusitania*.

Motors.—It is the general opinion that any one of several types of internal combustion motors at present available is suitable for use with dirigible balloons. With this type, lightness need not be obtained at the sacrifice of efficiency. In the aeroplane, however, lightness per output is a prime consideration, and certainty and reliability of action is demanded, since if by chance the motor stops, the machine must immediately glide to the earth. A technical discussion of motors would of itself require an extended paper, and may well form the subject of a special communication.

Propellers.—The fundamental principles of propellers are the same for air as for water. In both elements, the thrust is directly proportional to the mass of fluid set in motion per second. A great variety of types of propellers have been devised, but, thus far only the screw-propeller has proved to be of practical value in air. The theory of the screw-propeller in air is substantially the same as for the deeply submerged screw-propeller in water, and therefore does not seem to call for treatment here. There is much need at present for accurate aerodynamic data on the behavior of screw-propellers in air, and it is hoped that engineers will soon secure such data, and present them in practical form for the use of those interested in airship design.

Limitations.—Euclid's familiar "square-cube" theorem connecting the volumes and surfaces of similar figures, as is well known, operates in favor of increased size of dirigibles, and limits the possible size of heavier-than-air machines in single units and with concentrated load.

It appears, however, that both funda-

mental forms of aerial craft will likely be developed, and that the lighter-than-air type will be the burden-bearing machine of the future, whereas the heavier-than-air type will be limited to comparatively low tonnage, operating at relatively high velocity. The helicopter type of machine may be considered as the limit of the aeroplane, when by constantly increasing the speed the area of the supporting surfaces is continuously reduced until it practically disappears. We may then picture a racing aeroplane propelled by great power, supported largely by the pressure against its body, and with its wings reduced to mere fins which serve to guide and steady its motion. In other words, starting with the aeroplane type, we have the dirigible balloon on the one hand as the tonnage increases, and the helicopter type on the other extreme as the speed increases. Apparently, therefore, no one of these forms will be exclusively used, but each will have its place for the particular work required.

George O. Squier

MOSQUITO EXTERMINATION WORK IN NEW JERSEY

Professor John B. Smith, in his report to the governor on the work carried on under the law of 1906, shows that up to the end of the summer of 1908 there had been drained 20,292 acres of salt marsh extending from the Hackensack River to the mouth of Toms River on Barnegat Bay. To accomplish this, required 2,723,974 feet of ditching, put in at an actual cost of $44,058, some $12,000 being expended for administration, surveys and other work necessary to control the actual carrying out of the contracts.

During the same period of two years municipalities throughout the state have joined in the mosquito crusade, and have expended considerable sums of money for local work in eliminating breeding areas. The work is all in the direction of permanent improvement and of destroying the breeding localities. Oiling and temporary work is done only when it is necessary to destroy a brood of wigglers that might otherwise hatch before permanent work can be done.

The results have been very gratifying and the migrating marsh mosquitoes were almost entirely absent during most of the summer from the larger cities where drainage work had been done in 1907 or earlier. It developed in the course of the work that the eggs of these salt marsh species retain their vitality for a very long period and that for at least three years after a marsh is drained, there may be ever lessening broods of larvæ found whenever it becomes water-covered by freshet tides or heavy rains. This was interestingly shown by examinations of marsh mud, from areas drained for different periods, and counting the eggs and egg shells on the samples. It is, therefore, a rather slow process to completely clean up such areas, because a few specimens developing under favorable circumstances will provide a small stock of eggs that require three years or more to work out altogether. In the areas drained in 1904, however, practically no eggs were found except in the deepest depressions, and even in these they were very few in number and much scattered.

The season of 1908 was remarkable for the excessive rainfall in early spring, which provided breeding areas for the early brood, far beyond usual conditions, and these afterward concentrated in cisterns, water-barrels, sewer catch-basins and similar localities so that cities were much troubled by them in the entire region where these excessive spring rains prevailed.

If the legislature now in session provides sufficient means, it is expected that the drainage work can be carried to Great Bay during the season of 1909, and in the cities the local committees are already providing against a duplication of last season's experience with the house mosquito.

THE AMERICAN MUSEUM OF NATURAL HISTORY

The annual meeting of the trustees of the American Museum of Natural History was held on Monday, February 8. The following officers were elected: Henry Fairfield Osborn,